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Performance evaluation of Dynamic Block Error target selection based on traffic types in High Speed Uplink Packet Access

Master's Thesis submitted in partial fulfillment of the degree of Master of Science in Technology

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AALTO UNIVERSITY **ABSTRACT OF THE MASTER'S THESIS**

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In today's internet oriented world, the growth in mobile or cellular data traffic is enormous and the trend is going to continue for years to come. From past few years, the uplink data traffic has been of much importance because of the rise in social networking, video-conferencing, web-browsing etc. Therefore, uplink cell capacity and user experience are the major factors that the operators need to focus on.

In uplink, users are not orthogonal to each other. Therefore, it results in interference when multiple users transmit simultaneously. That means to say, in uplink, shared resource is the amount of interference within the cell. Power control is a very important aspect in uplink to control the transmission power of UE's and thus the resulting interference.

In High Speed Uplink Packet Access (HSUPA), a feature called 'Dynamic Block error rate target selection' is introduced to control the uplink interference. This feature distinguishes the users into different traffic types based on their bit rate, frame rate and block error rate. Depending on the traffic types, different ideal BLER (Block error rate) targets are used to calculate the power with which the UE has to transmit in the next transmission period so as to introduce minimum interference. This thesis is focused on studying the 'Dynamic BLER' feature and then implementing different outer loop power control algorithms related to the feature. Simulations are done for various scenarios (low traffic, moderate traffic, high traffic) within the cell and the gain achieved in terms of cell throughput from this feature is verified through results for all the scenarios.

Keywords: Block error rate, Signal to interference ratio, Outer loop power control, Radio resource management, uplink interference.

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List of Abbreviations

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
ARQ	Automatic Repeat Request
BLER	Block Error Rate
BMC	Broadcast/Multicast
CN	Core Network
CQI	Channel Quality Indicator
CRC	Cyclic Redundancy Checksum
CS	Circuit Switched
DPCCH	Dedicated Physical Control Channel
E-AGCH	Enhanced Absolute Grant Channel
E-DCH	Enhanced Dedicated Channel
E-DPCCH	Enhanced Dedicated Physical Control Channel
E-DPDCH	Enhanced Dedicated Physical Data Channel
E-HICH	Enhanced HARQ Indicator Channel
E-RGCH	Enhanced Relative Grant Channel
E-TFC	E-DCH Transport Format Combination
EDGE	Enhanced Data rates for GSM Evolution
FEC	Forward Error Correction

FP	Frame Protocol
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
HARQ	Hybrid Automatic Repeat Request
HS-DPCCH	High Speed Dedicated Physical Control Channel
HSDPA	High Speed Downlink Packet Access
HSUPA	High Speed Uplink Packet Access
ILPC	Inner Loop Power Control
IP	Internet Protocol
MAC	Medium Access Control
MEHO	Mobile Evaluated Handover
MIMO	Multiple Input Multiple Output
NEHO	Network Evaluated handover
NRT	Non Real Time
OLPC	Outer Loop Power Control
P-CPICH	Primary Common Pilot Channel
PDCP	Packet Data Convergence Protocol
PRACH	Primary Random Access Channel
PS	Packet Switched
RAB	Radio Access bearer
RLC	Radio Link Control
RNC	Radio network Controller
RRC	Radio Resource Control
RRM	Radio Resource Management
RSCP	Received Signal Code Power

RTWP	Received Total Wideband Power
SDU	Service Data Unit
SF	Spreading Factor
SIR	Signal to Interference Ratio
SRB	Signalling Radio Bearer
TCP	Transmission Control Protocol
TTI	Transmission Time Interval
UE	User Equipment
UMTS	Universal Mobile Telecommunications Systems
UTRAN	UMTS Terrestrial Radio Access Network

Chapter 1

Introduction

The first chapter gives a background on the thesis work and also defines the problem statement for the thesis. This chapter also gives a clear perspective to the reader about the scope of the thesis. The last section of this chapter gives an outline on the structure of the thesis.

1.1 Background

Mobile communication systems have undergone significant changes over the past few decades. Cellular networks have evolved from the basic 1G (First Generation) analogue network or voice-only network, to 2G (Second generation) digital networks with text, multimedia messaging and data transfers with low speeds focusing on capacity and coverage, to 3G (Third Generation) or UMTS (Universal Mobile Telecommunications System) networks with data delivery rates of 384Kbps to 2Mbps focusing on true mobile broadband experience. The deployment of 4G (Fourth Generation) networks or the all IP (Internet Protocol) networks has widely increased in recent times and data rates of 100Mbps to 1Gbps are being achieved which provides access to wide range of mobile applications and services. The advancement in the wireless access technologies are to cater to the customer needs [1].

Mobile network traffic is increasing rapidly year after year and by 2017 more than 90% of the world is said to have 2G connections, 85% of the world is said to have 3G connections and 50% is said to have 4G connections [2]. The reason for this tremendous growth is the availability of innovative mobile applications like video conferencing, gaming, internet banking, mobile TV, streaming, social networking, health monitoring etc which has revolutionized the way people communicate [3].

The cellular networks should keep up with the growing demand for mobile traffic. 4G networks are undoubtedly far better than 3G in terms of speed, usability etc. But, since 4G networks are still not widely deployed all over the world and also since 4G networks tend to have shorter coverage range in some parts of the world, it is necessary to maintain and optimize the 3G networks for at least few more years. To cater to all the above mentioned requirements, an enhanced version of 3G communication networks is introduced to have higher data speeds and capacity. In downlink, the enhanced 3G version is called high speed downlink packet access, reaching data rates of around 100 Mbps with the use of multiple carrier and MIMO (Multiple Input Multiple Output) technologies [4]. In uplink, the enhanced version is called high speed uplink packet access, reaching data rates of around 35 Mbps with the use of MIMO and higher modulation technologies [5].

In HSDPA (High Speed Downlink Packet Access), such high data rates are possible due to the new functionalities such as fast scheduling, fast retransmissions, adaptive modulation and coding, extended multi-code transmissions etc. In downlink, since channelization codes are the limiting factor for capacity, all these new functionalities make efficient use of channelization codes and thus increases downlink capacity [6]. In HSUPA (High Speed Uplink Packet Access), such high data rates are possible due to fast scheduling, fast retransmissions, multi-code transmissions, shorter transmission time interval etc. In uplink, since interference is the limiting factor for capacity, these new functionalities reduce the overall interference of the system and thus increase the uplink capacity [7].

In HSUPA, since interference is the capacity limiting factor, efficient power control mechanisms can reduce the interference resulted from each user in uplink. The power control procedure involves measuring the quality of the channel or transport block error rate in fixed time intervals. Based on the measurements, an algorithm is used to define the base station output power for each user, to achieve sufficient uplink quality of service in the subsequent transmissions. The base station output power for each user is calculated depending on the target SIR (Signal to Interference Ratio) required as defined by outer loop power control. Target SIR is calculated based on the measured BLER (Block Error Ratio) and ideal BLER target set during radio network planning [8]. Nokia Networks has introduced a new feature called 'Dynamic HSUPA BLER' which has an efficient power control algorithm to define and to modify the base station output power granted for each HSUPA user dynamically, depending on the channel quality and the type of uplink data transmission. It classifies the user into different traffic types based on the frame rate and FP (Frame Protocol) bit rate, and then uses different ideal BLER target values for each traffic type to determine the target SIR required for achieving sufficient uplink quality. The overall gain achieved from this new feature is the improvement in cell throughput due to the reduction of uplink interference within the cell [9]. The feature is better understood in the following chapters.

1.2 Scope of Thesis work

The thesis work is focused on evaluating the performance improvement provided by 'Dynamic HSUPA BLER' feature. Firstly, we discuss about the feature from implementation point of view. Then, we compare the results of with and without the feature by implementing a simulator to calculate the cell throughput and average user throughput. Then, we discuss the two shortcomings of the feature under very low traffic and very high traffic in the cell. Then, we discuss the solutions to those problems with the help of another simple simulation. We then determine the gain in cell throughput before and after the solution for those problems.

We also discuss on some of the questions mentioned below in the coming chapters:

Why 'Dynamic HSUPA BLER' feature? What is the gain achieved in terms of cell throughput? What are the other factors to be considered to gain maximum outcome from the feature? How are those factors taken care off?

1.3 Outline of the Thesis

The structure of the thesis is mentioned below:
Chapter 2 gives an introduction to high speed uplink packet access system architecture and protocol architecture. It also explains all the new principles introduced in HSUPA along with the description of new channels introduced. Also explained are the radio resource management algorithms like power control, handover control, load control, admission control, packet scheduler etc. This chapter forms a basis for understanding the entire thesis. Chapter 3 describes the 'Dynamic HSUPA BLER' feature from the implementation point of view. The major modifications are involved in outer loop power control algorithms and are discussed thoroughly. Chapter 4 describes the methodology of implementing the simulator needed to evaluate 'Dynamic HSUPA BLER' feature. Chapter 5 describes the simulation results and also discusses on the solutions for the already mentioned shortcomings of the feature. Chapter 6 gives the conclusion for the thesis work.

Chapter 2

High Speed Uplink Packet Access

The aim of this chapter is to introduce the functionality changes in HSUPA with respect to Release 99, explain the protocol architecture of R99 and HSUPA and also to explain various principles involved in HSUPA. This chapter also gives a general overview on radio resource management functionalities.

2.1 3GPP

The term 3GPP stands for 'Third Generation Partnership Project'. 3GPP is a telecommunication forum and their sole purpose is to create technical specifications and technical reports for a 3rd generation mobile system based on the evolved GSM (Global System for Mobile Communication Networks) core networks and the radio access technologies supported. 3GPP also has the responsibility of approving and maintaining the specifications and reports which are to be used globally.

Table 2.1 shows different releases of 3GPP along with the year of release. Release 99 was the first 3gpp specification for UMTS 3G networks. Further releases include the modification or addition of new functionalities to the already existing specifications [10].

Release 99	**Release 4**	**Release 5**	**Release 6**	**Release 7**	**Release 8**	**Release 9**
2000	2001	2002	2004	2007	2008	2009

Table 2.1: 3GPP release timeline

2.2 UMTS architecture

The high level system architecture of UMTS mainly consists of three basic elements: CN (Core Network), which handles the switching and routing of CS (Circuit Switched) calls also providing various services to the customers; UTRAN (UMTS terrestrial radio access network), which manages all the radio related functionalities; and UE (user equipment), which is a device used to connect to the network via air interface. Figure 2.1 shows the basic elements and the interfaces connecting them [11].

Figure 2.1: UMTS system level architecture

The interface between UE and UTRAN is called Uu which is an external interface and the interface between UTRAN and CN is called Iu. For HSUPA, the major modifications are done in UE, UTRAN and Uu interface.

2.3 Standardization of HSUPA

HSUPA was introduced in release 6 of 3GPP. The official name of HSUPA is enhanced uplink. The main goal of HSUPA was to increase the uplink data rates and uplink capacity, so as to match with that of HSDPA (in downlink) which was introduced in release 5. The main functionalities of HSUPA introduced in release 6 are

1. Fast physical layer HARQ (Hybrid Automatic Repeat Request) for uplink
2. Node B based uplink scheduling
3. Shorter uplink transmission time interval

Table 2.2 shows the differences involved in R99, HSDPA and HSUPA features [11].

Feature	Release 99 DCH	HSDPA	HSUPA
Multi-code transmissions	Yes	Yes	Yes
Variable spreading factor	Yes	No	Yes
Soft handover	Yes	No	Yes
Fast power control	Yes	No	Yes
Adaptive modulation	No	Yes	No
Node B scheduling	No	Yes	Yes
Fast L1 HARQ	No	Yes	Yes
Shorter (2 ms) TTI	No	Yes	Yes
Theoretical maximum data rate	2 Mbps (UL/DL)	14.4 Mbps (DL)	5.76 Mbps (UL)

Table 2.2: Comparison of R99, HSDPA and HSUPA

2.4 R99 and HSUPA architecture for UTRAN

UE uses air interface Uu to communicate with Node B. Node B uses Iub interface to communicate with RNC (Radio Network Controller). RNC uses Iu interface to communicate with core network. UTRAN mainly includes 2 elements: Node B and RNC. There is also an Iur interface between RNC's for inter-RNC communication. UTRAN mainly includes 2 elements: Node B and Radio Network Controller. One RNC can handle the operation of several Node Bs using Iub interface.

The UE initially connects to a particular RNC and it becomes serving RNC. If the UE now moves to a cell edge, soft handover occurs and the UE is now controlled by a different RNC. This RNC now becomes drift RNC. Figure 2.2 shows the architecture of UTRAN and the involved interfaces. Table 2.3 describes the different RRM (Radio Resource Management) functionalities involved in UTRAN for R99 [11].

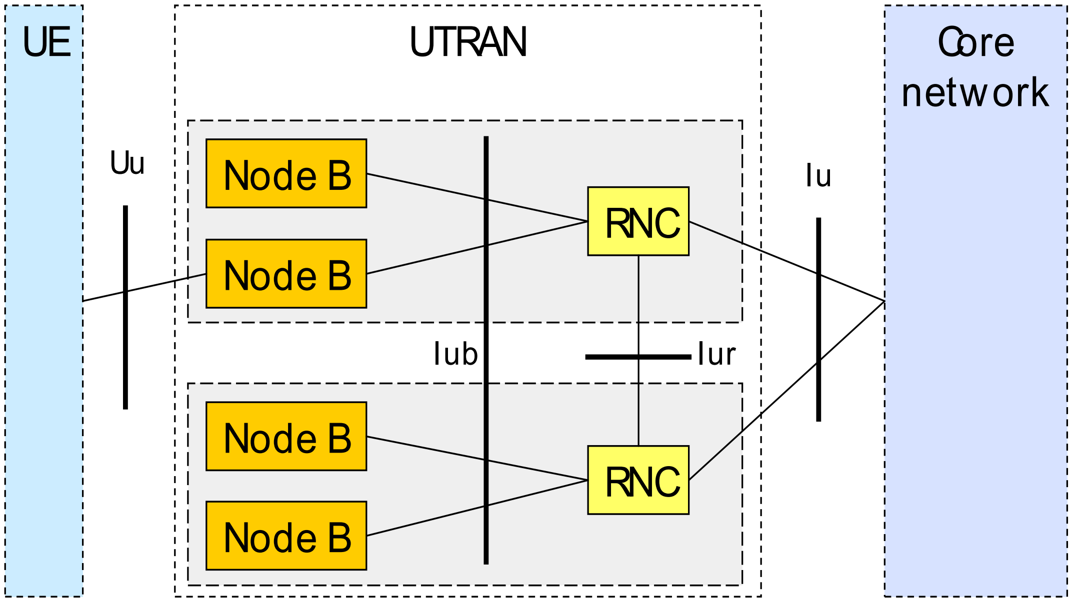

Figure 2.2: UTRAN architecture

Node B	Drift RNC	Serving RNC
Power control	Admission control	QoS parameters mapping
	Initial power and SIR setting	Scheduling for dedicated channels
	Radio resource reservation	Handover control
	Scheduling for common channels	Outer loop power control
	DL code allocation and code tree handling	
	Congestion control	

Table 2.3: RRM functionalities in UTRAN for R99

UTRAN architectural changes for HSUPA include:

1. Moving the functionality of packet scheduling from RNC to Node B
2. Introduction of dynamic resource allocation in Node B
3. Introduction of congestion control in Node B
4. Introduction of physical layer retransmissions in Node B.

Table 2.4 describes the different functionalities involved in UTRAN for HSUPA [11].

Node B	Drift RNC	Serving RNC
Fast power control	Admission control	QoS (Quality of Service) parameters mapping
Packet scheduling	Initial power and SIR setting	Handover control
Dynamic resource allocation	Radio resource reservation for HSUPA	Outer loop power control (HSUPA)
Congestion control	DL code allocation and code tree handling	
Retransmissions	Overall congestion control	

Table 2.4: RRM functionalities in UTRAN for HSUPA

2.5 Protocol layer architectural changes in HSUPA

2.5.1 R99 radio protocol architecture

R99 radio protocol architecture can be divided into three layers: physical layer or Layer 1; data link layer or Layer 2; and network layer or Layer 3.

Layer 1 is mainly responsible for processing the transport blocks received from higher layers and then transmitting them over the radio interface. Therefore its main tasks include source coding, channel coding, interleaving, rate matching, modulation, spreading, scrambling, inner loop power control, micro-diversity combining etc. Physical layer offers services to higher layers through transport channels [12].

Layer 2 includes several sub layers called MAC (Medium Access Control) protocol, RLC (Radio Link Control) protocol, PDCP (Packet Data Convergence) Protocol and BMC (Broadcast Multicast) protocol [12].

The main tasks of MAC include multiplexing of several UE’s to the shared radio resource, mapping and multiplexing of logical channels within one UE to transport channels, prioritizing between services of same UE, prioritizing between different UE’s, traffic volume measurements, channel type switching, ciphering and selecting suitable transport format for each transport channel. MAC offers transport layer services to its higher layers through logical channels.

The main tasks of RLC include segmentation and reassembly of control and user data, concatenation, padding, duplicate avoidance and removal, sequence number checking, SDU (Service Data Unit) discard, error correction or retransmission, flow control and ciphering. RLC offers services to its higher layers. RLC can provide three kinds of services to a logical channel:

1. Transparent mode, where header is not added to data in RLC.
2. Unacknowledged mode, where flow control RLC retransmissions are not possible.
3. Acknowledged mode, where flow control and RLC retransmissions are enabled.

PDCP is used mainly for compressing the user data such as IP header compression and in sequence delivery of packet data, whereas BMC is used mainly for cell broadcasting and multicast broadcasting services.

Layer 3 consists of RRC (Radio Resource Control) protocol which handles all the procedures such as establish, reconfigure and release of radio bearers as well as RRC connections between UE and UTRAN. Other main services of RRC protocol include broadcasting system information, paging, initial cell selection and reselection, transport of non access stratum control messages, security control procedures, UE measurement reports, RRC connection mobility functions etc. RRC protocol also has control interfaces to all the lower level protocols which help in controlling the data transfer [12]. Figure 2.3 shows the radio interface protocol architecture [13].

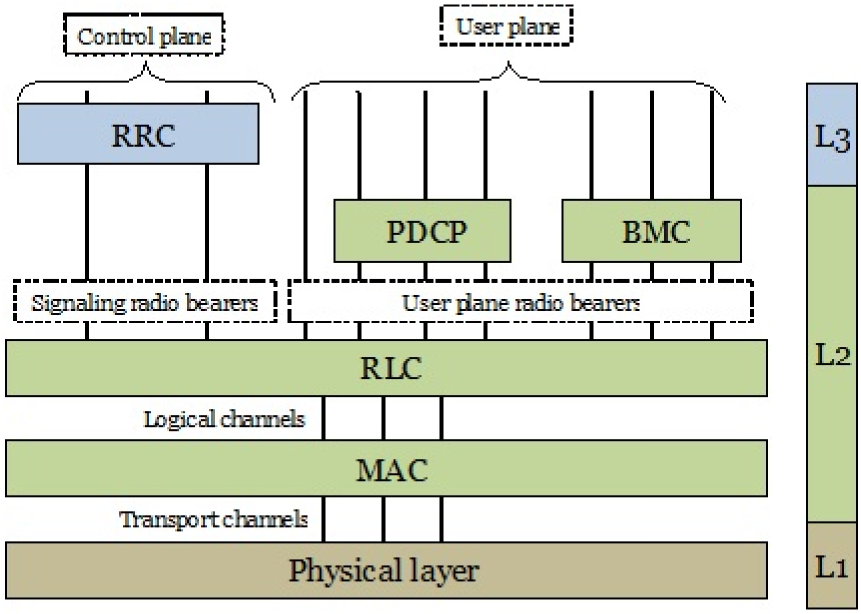

Figure 2.3: Radio interface protocol architecture

2.5.2 HSUPA protocol architectural changes

The major change in HSUPA is the movement of scheduling functionality from RNC to Node B. Scheduling is MAC layer functionality and therefore a new MAC layer protocol is needed in the Node B which is called MAC-e. There is also a new MAC-es layer protocol introduced in RNC which is used for packet reordering if the packets are received out of order due to retransmissions. Physical layer has also undergone some changes due to the introduction of layer 1 retransmissions in Node B. MAC-e/MAC-es protocol is also introduced in UE to select suitable transport format and also to handle physical layer retransmission functionality. RLC retransmissions in RNC are still used in HSUPA as a backup for physical layer retransmissions. Figure 2.4 shows the detail picture of HSUPA user plane protocol architecture [13].

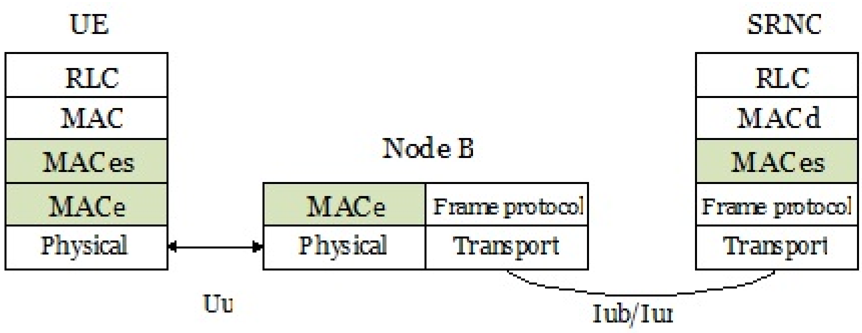

Figure 2.4: *HSUPA User plane protocol architecture*

2.6 HSUPA principles

As mentioned earlier, HSUPA introduces some new functionality like Node B scheduling, fast L1 HARQ and shorter TTI (Transmit Time Interval) being the major ones. These functionalities help in increasing end user throughput, increasing system capacity and reducing latency.

2.6.1 Fast layer 1 HARQ

Before understanding HARQ, let us try to understand the functionality of automatic repeat request and forward error correction. In ARQ (Automatic Repeat Request), if the receiver detects an error the data is discarded and requests for a retransmission of the same data. They are highly reliable but throughput decreases under bad channel conditions. In FEC (Forward Error Correction), error correcting code is used in the receiver to take care of the transmission errors. Since no retransmissions are used system becomes highly unreliable but throughput remains constant.

To overcome the drawbacks of ARQ and FEC, we introduce HARQ. HARQ is a combination of both ARQ and FEC. Two HARQ schemes are available, chase combining and incremental redundancy. In chase combining, the erroneous packets are combined with the retransmitted packets that are identical to the original packets. In incremental redundancy, the erroneous packets are combined with the retransmitted packets which include additional redundancy along with or without the original packet.

In HSUPA, ARQ is implemented in RLC layer of RNC whereas HARQ is implemented in physical layer of Node B. Therefore, delays due to physical layer retransmissions are much less compared to RLC retransmissions. Thus, physical channels can operate at higher error rate which can increase system capacity. Due to the physical layer retransmissions, RLC retransmissions are significantly low.

HARQ in HSUPA is synchronous, that means the time required for the retransmission after the first erroneous transmission is fixed. The number of parallel HARQ processes in 2ms TTI is 8, whereas in 10ms TTI it is 4. The time required for the retransmission of a packet is 16ms in 2ms TTI and 40 ms in 10ms TTI. Figure 2.5 gives an overall picture of ARQ and HARQ in HSUPA [13].

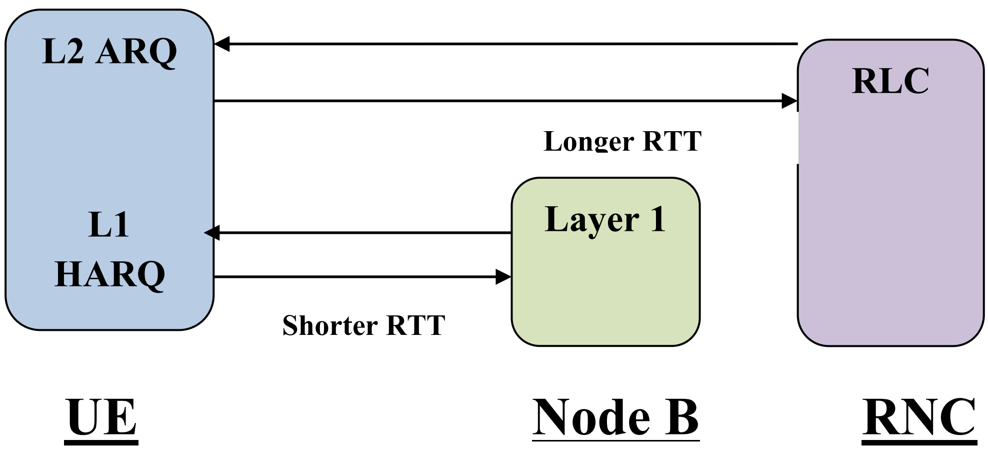

Figure 2.5: ARQ and HARQ in HSUPA

2.6.2 HSUPA Node B scheduling

In HSUPA, scheduling is done in Node B where the physical layer information is readily available. This results in reducing the delay in scheduling operations and optimizing the resources efficiently. In uplink, each UE has its own transmitter and therefore an algorithmic approach is needed in uplink scheduling. The shared resource in uplink is the total received power (noise rise) as seen in Node B [14]. There are two types of scheduling:

1. Rate scheduling, where all the users are scheduled in every TTI by reducing the data rates of all users to take care of the uplink interference target level.
2. Time scheduling, where only users who have data to transmit are scheduled every TTI taking care of the uplink interference target level.

In HSUPA, scheduling operation takes place in MAC layer. UE sends happy bit to Node B indicating if it can transmit at a higher data rate than currently allocated or not. Node B which has information about uplink noise rise and power levels, decides to increase or decrease the power granted to UE. The UE correspondingly adjusts its transmission power.

2.6.3 Two TTI lengths in HSUPA

HSUPA supports both 2 ms and 10 ms transmission time intervals. The shorter TTI of 2ms is used to reduce the delay caused by retransmissions compared to 10ms TTI. If the number of retransmissions increases significantly as in the case of cell edge user, downlink signalling power increases and hence Node B consumes a lot of transmission power. Therefore it is necessary to have 10 ms TTI for cell edge users in HSUPA where the downlink signalling can be reduced compared to 2 ms TTI [14].

2.6.4 HSUPA channels

In HSUPA, UE has a new dedicated uplink transport channel E-DCH (Enhanced Dedicated Channel) in the uplink. It supports enhanced features as compared to that of DCH (Dedicated Channel). The two major differences between E-DCH and DCH are:

1. A UE can have only one E-DCH transport channel whereas it can have multiple DCH transport channels configured.
2. HARQ functionality is supported for E-DCH.

The E-DCH transport channel is now mapped to multiple E-DPDCH (Enhanced Downlink Physical Data Channel) uplink physical channels for physical layer transmission. Both DCH and E-DCH can co-exist in the same UE since both are working in parallel. The E-DPCCH (Enhanced Downlink Physical Control Channel) is sent in parallel to E-DPDCH which carries all the control information of E-DPDCH. There also exist three new downlink physical channels E-HICH (Enhanced HARQ Indicator Channel), E-RGCH (Enhanced Relative Grant Channel) and E-AGCH (Enhanced Absolute Grant Channel) for HARQ indication and scheduling purposes [14].

2.6.4.1 E-DCH dedicated physical data channel

E-DPDCH is an uplink physical channel used for transmitting data received from E-

DCH transport channel. E-DPDCH exists in parallel with DPDCH, DPCCH and HS-DPCCH of R99. E-DPDCH supports physical layer HARQ, Node B scheduling, minimum spreading factor of 2, TTI lengths of 2ms and multi-code transmission. E-DPDCH is transmitted in parallel with DPCCH as it needs information on SIR, power control bits and channel estimation.

2.6.4.2 E-DCH dedicated physical control channel

E-DPCCH is an uplink physical channel used for carrying out-of-band information about E-DPDCH. E-DPCCH uses a spreading factor of 256 and carries information such as E-TFCI (Enhanced Transport Format Combination Indicator) which indicates the transport format combination, RSN (Retransmission Sequence Number) which indicates the HARQ sequence number of the transport block and happy bit which indicates if the UE can transmit with higher power or not.

2.6.4.3 E-DCH HARQ indicator channel

E-HICH is a downlink physical channel used to send ACK or NACK for every E-DPDCH data transmitted in uplink i.e. for every TTI.

2.6.4.4 E-DCH relative grant channel

E-RGCH is a downlink physical channel used to increase or decrease the uplink transmission power of E-DPDCH every TTI. The change in transmission power happens in small steps.

2.6.4.5 E-DCH absolute grant channel

E-AGCH is a downlink physical channel used to transmit the absolute maximum transmission power value based on the Node B scheduler. This is the maximum power with which the UE can transmit data in E-DPDCH.

2.7 Radio Resource management algorithms

Radio Resource Management is a mechanism in the cellular communication systems, which uses different algorithms to optimize the radio resource utilization by controlling the system level co-channel interference and other radio transmission characteristics, to serve the user with a better quality of service [11].

HSUPA RRM includes functionalities in RNC, Node B and UE. HSUPA RRM in RNC is responsible for allocating resources to both DCH and E-DCH users. HSUPA RRM in Node B is responsible for sharing the resources between different HSUPA UE's. HSUPA RRM in UE is responsible to choose the transport block size based on the resources allocated to it by Node B and also based on the buffer size. Figure 2.6 describes all the RRM functionalities of HSUPA in general [11].

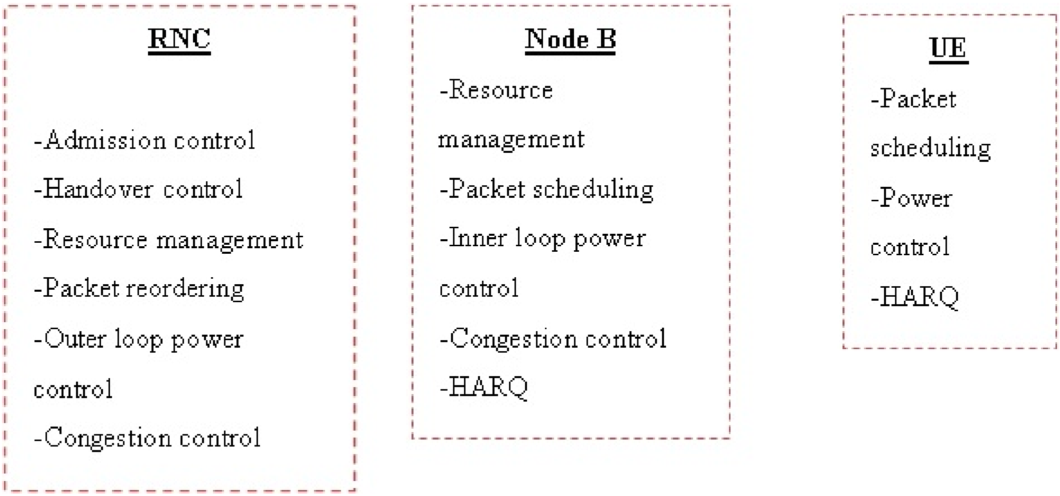

Figure 2.6: RRM functionalities in HSUPA

2.7.1 Resource management

Noise rise is defined as the ratio of total received wideband power to the noise power. The received power consists of intra-cell interference from DCH and E-DCH connections, inter-cell interference and thermal noise. RNC defines the maximum uplink interference target or the noise rise for the Node B based on the radio network planning. The resources for DCH connections (scheduled and non-scheduled) are managed by RNC and the resources for E-DCH connections are managed by Node B. Resource allocation control with HSUPA is shown in figure 2.7 [11].

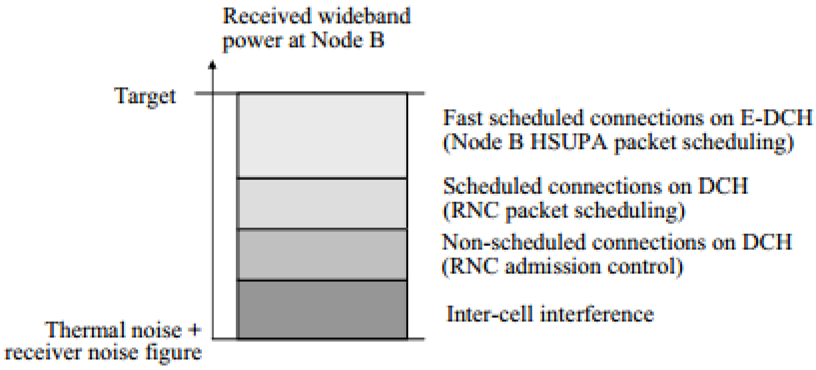

Figure 2.7: Resource allocation control with HSUPA

2.7.2 Admission control

Admission control is used to maintain stability and to achieve high traffic capacity. The admission control algorithm is executed whenever a new radio access bearer is set up or if the existing radio bearer is modified. It is also executed during all kind of handovers. This algorithm estimates the uplink interference level increase caused by the establishment of a new radio bearer in the network and decides whether to admit the bearer into the network or not. Load change estimation is also done in the adjacent cells to measure the inter-cell interference effect. The decision is based on the threshold levels set during the radio network planning [15].

Admission control decision depends on number of factors like uplink interference limit measured by RTWP (Residual Total Wideband Power), number of maximum HSUPA users allowed by RNC, scheduling priority indicator of the new call to be set up, guaranteed bit rate for a new call to be set up, resource availability for HSDPA when a new HSUPA user is setup etc.

2.7.3 Load control and congestion control

If the system becomes overloaded, the load control algorithm returns the system quickly back to the normal load state as defined by the radio network planning. The load control can be divided into preventive load control (e.g. congestion) and the overload control (e.g. dropping of calls in worst case). Basic difference between the preventive and the overload control actions is that the former is performed before the cell is overloaded and the latter is performed after the cell is overloaded. These actions are performed by measuring both uplink and downlink interference periodically in the cell level.

The UMTS wireless services are characterized into real time (e.g. VoIP, video streaming etc) and non-real time services (web-browsing etc). The proportion between real time and non-real time traffic varies all the time. The load caused by real time traffic cannot be controlled and therefore the remaining capacity is reserved for the best effort non real time traffic. The interference caused by the surrounding cells together with the real time traffic is called non controllable traffic. Best effort non real time traffic is called controllable traffic. The load control is performed for the uplink and downlink separately because the 3rd generation supports almost 100 % asymmetric traffic, and the load may vary a lot between uplink and downlink. The load control can drop the controllable and semi-controllable power to zero if required. The serving RNC can also send a congestion indication signal to Node B if the transport network is congested. Figure 2.8 shows the basic principle for the load control thresholds [11].

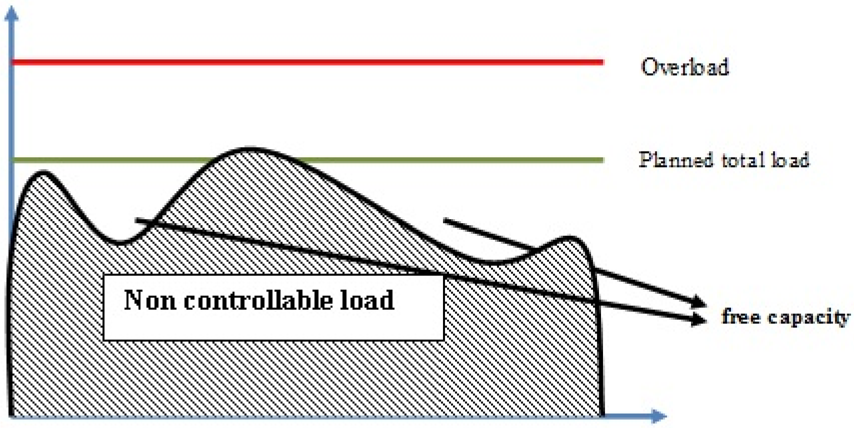

Figure 2.8 Load control thresholds

2.7.4 Handover control

The handover control in the radio access network supports two types of handover: soft handover and hard handover.

Soft handover is a mobile evaluated handover. The mobile station continuously measures the signal levels from the serving and the neighbouring base stations indicated by the RNC. When the signal levels crosses the handover threshold limits set by RNC, the mobile station sends a measurement report to the RNC. Now, the RNC decides whether to add or remove cells from the mobile stations active set [11].

The following types of soft handovers are supported:

I. Handover between cells within one base station called softer handover.
II. Handover between base stations within one RNC called intra-RNC soft handover.
III. Handover between base stations controlled by separate RNC's called inter-RNC soft handover.

Hard handover is classified into inter-frequency and intra-frequency hard handovers. Intra-frequency hard handover is a mobile evaluated handover while inter-frequency hard handover is a network-evaluated handover. Hard handover is lossless for non real time radio bearer but it causes a short disconnection for real time radio bearer.

2.7.5 Transport format selection by UE

The transport format selection is done in MAC layer of UE. The UE receives information on the supported transport block sizes and the corresponding power offset values required to transmit the selected transport block. UE also has information on the priorities of the logical channels, E-DCH buffer status and also the maximum power with which it can transmit. Now, UE receives scheduling grants from Node B via E-AGCH or E-RGCH indicating the maximum power offset with which the UE can transmit every TTI. Depending on the scheduling grant, UE chooses the highest possible E-TFC value [14]. Node B packet scheduling and HARQ functionalities are already explained in section 2.6

2.7.6 Power control

Power control is the most important and critical aspect of radio resource management, especially in uplink. In uplink, since all the users transmit at the same time within the same frequency, each one of them becomes interference to the rest and vice versa.

Consider there are two mobile stations UE1 and UE2 operating within the same frequency. Also consider that both are transmitting at same powers, but UE1 is nearer to the base station compared to UE2. Therefore, Node B receives more power from

UE1 than UE2 which results in masking of UE2 and thus blocking a large part of the cell. This situation is called near-far problem and has to be controlled by efficient power control mechanism [11].

There are two power control mechanisms in HSUPA called open loop power control and closed loop power control.

2.7.6.1 Open loop power control

Open loop power control is performed in UE. In uplink open loop power control, UE measures the RSCP (Received Signal Code Power) of the active P-CPICH (Primary Common Pilot Channel) and some control parameters are transmitted by Node B on broadcast channel. The RSCP of CPICH is inversely proportional to the distance between UE and Node B. Based on this information, UE can estimate the path loss and thus the distance from the Node B. This helps in determining the required initial power for the first RACH (Random Access Channel) preamble to be transmitted, using equation (2.1) given below [16].

$$Initial\ Power = CPICH_{Tx_{Pwr}} - CPICH_{RSCP} + UL_{int} + UL_{CI} \tag{2.1}$$

Where $CPICH_{TXpwr}$ is the downlink transmit power, UL_{int} is the uplink interference and UL_{CI} is the required carrier to interference ratio for uplink.

2.7.6.2 Closed loop power control

Closed loop power control operates both in uplink and downlink and it is a combination of inner and outer loop power control functionalities. The inner loop power control operates between User equipment and Node B. It controls the transmitted power of the UE to keep the received signal to interference ratio close to the target SIR. The target SIR is set by outer loop power control by measuring the quality of uplink data transmission. Quality is measured by calculating block error rate of the data frames sent by UE.

2.7.6.2.1 Inner closed loop power control (ILPC)

Inner closed loop power control is also known as fast closed loop power control. In ILPC, Node B measures the uplink signal quality indicated by SIR and compares it with the target SIR set by OLPC. If measured SIR is less than the target SIR, transmit power control command '1' indicating UE to increase transmit power is sent, otherwise '0' indicating UE to decrease transmit power is sent. Now the UE adjusts its transmission power based on the transmit power control commands received from Node B [17].

2.7.6.2.2 Outer closed loop power control (OLPC)

Outer loop power control is responsible to determine the minimum target SIR that is required for sufficient quality of the connection. OLPC sets the target SIR value according to the received BLER or Bit Error Rate. In uplink, OLPC sets the target SIR for each uplink fast closed loop power control in Node B. Thus each UE has a different target SIR value based on their uplink data transmission quality. Figure 2.9 explains the outer closed loop power control procedure in general [9].

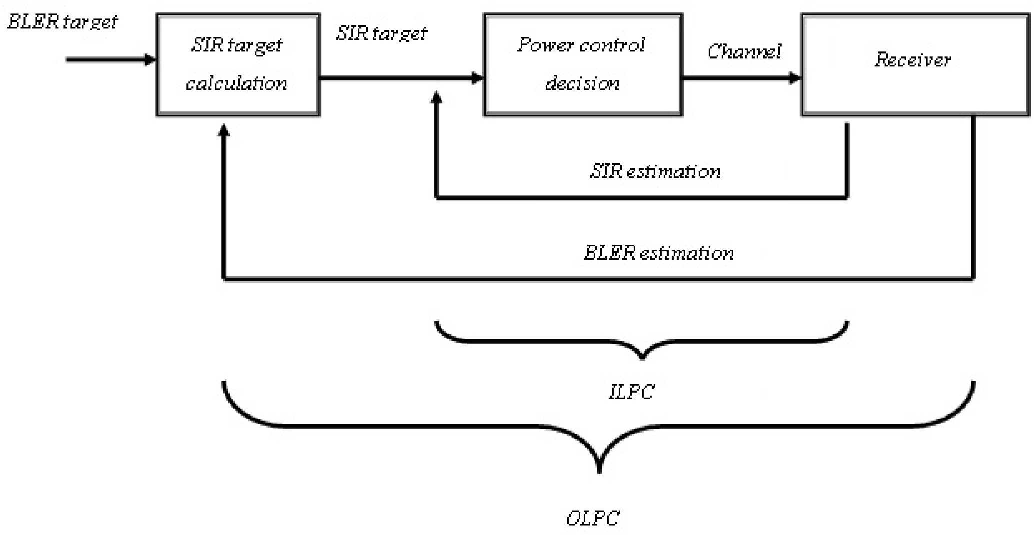

Figure 2.9: Outer loop power control

Chapter 3

‘Dynamic HSUPA BLER’ overview

3.1 Description

In uplink, interference limits the capacity of a cell, and therefore it is necessary to share the uplink interference among HSUPA users within a cell in an optimized way. ‘Dynamic HSUPA BLER’ feature provides one such possibility by differentiating the HSUPA users into different traffic types based on several inputs such as frame rate, FP bit rate and number of HARQ retransmission information [18]. Outer loop power control of radio resource management module in RNC takes this responsibility of distinguishing the users. The frame rate information is obtained from the BLER window implementation in OLPC. It is explained clearly in later sections of this chapter. FP bit rate information is received from MAC-es module by calculating the data rate over complete frame window period. The number of HARQ retransmissions required to successfully transmit a transport block in uplink is obtained from HARQ module. The other job of OLPC is to measure the block error ratio of PS NRT bearers by checking the CRC (Cyclic Redundancy Check) values of each transport block received.

Classification of traffic types is based on the following three criteria’s and the corresponding ideal BLER target values chosen are also mentioned below [9]:

1. If the percentage of UE packets in FP frame is greater than 90%, then we say that the PS NRT bearers can achieve peak data rates close to the bearer maximum. This type of user is classified into peak traffic type and ideal BLER target of 8% is used after zero HARQ retransmissions.

2. If the number of FP frames per second is less than or equal to 10 in case of 10ms TTI or less than or equal to 50 in case of 2ms TTI, then we say that the UE is transmitting data in bursts. This type of user is classified as bursty traffic type and ideal BLER target of 10% is used after 0 HARQ retransmissions.

3. If the number of FP frames per second are greater than 10 in case of 10ms TTI or greater than 50 in case of 2ms TTI, then we say that the UE is transmitting data continuously. This type of user is classified as continuous traffic type and ideal BLER target of 10% is used after 1 HARQ retransmissions or we can say that ideal BLER target of $\sqrt{10} = 31.6\%$ is used after 0 HARQ retransmissions.

Once the traffic type, ideal BLER target value and the measured BLER value for a particular user is available, the target SIR is calculated for PS NRT bearers in the OLPC module. Initial target SIR is fixed depending on signalling RAB (Radio Access bearer) quality of the user. The other task of this feature is to check for the possibility of traffic type transition in the users by measuring the frame rate, FP bit rate and BLER in short fixed time intervals. If there is a traffic type transition happening, then respective ideal BLER target values are chosen dynamically and the target SIR is recalculated based on the number and type of services associated with the UE. The rules for traffic type transitions and target SIR recalculations are mentioned below [9]:

1. If traffic state changes from peak to bursty or continuous and if SIR target is greater than initial SIR target, then use initial SIR target as new SIR target.
2. If traffic state changes from bursty or continuous to peak and if SIR target is less than initial SIR target, then use initial SIR target as new SIR target.
3. If traffic state changes from bursty to continuous or vice versa and if SIR target is greater than initial SIR target, then use initial SIR target as new SIR target.

The above mentioned SIR target recalculations are done depending on the number and type of services associated with the UE. Some conditions to be followed are mentioned below [9]:

1. If UE has only one PS (Packet Switched) entity and an SRB (Signalling Radio Bearer) entity, PS entity can request for SIR target adjustment irrespective of its activity states.
2. If UE has more PS entities and an SRB entity, then only PS active entity can request for SIR target adjustment.
3. If the UE has one or more PS entities, one CS (Circuit Switched) entity and an SRB entity, then only PS active entity can request for SIR target adjustment.

The detailed description for all the above mentioned procedures can be well understood in section 3.2.

3.2 Functional split of OLPC module

OLPC in RNC is divided into number of OLPC entities and one OLPC controller that control all the entities. In context of one call, there may be several services and each service has a traffic channel associated with it. Therefore, one call will have several OLPC entities (equal to the number of services in that call plus an additional signalling OLPC entity) and one OLPC controller. In HSUPA, since the traffic channel E-DCH can be spread across multiple (maximum 4) physical channels and carried over the air interface, there are 4 additional E-DCH OLPC entities. Figure 3.1 shows the functional split of uplink OLPC [16].

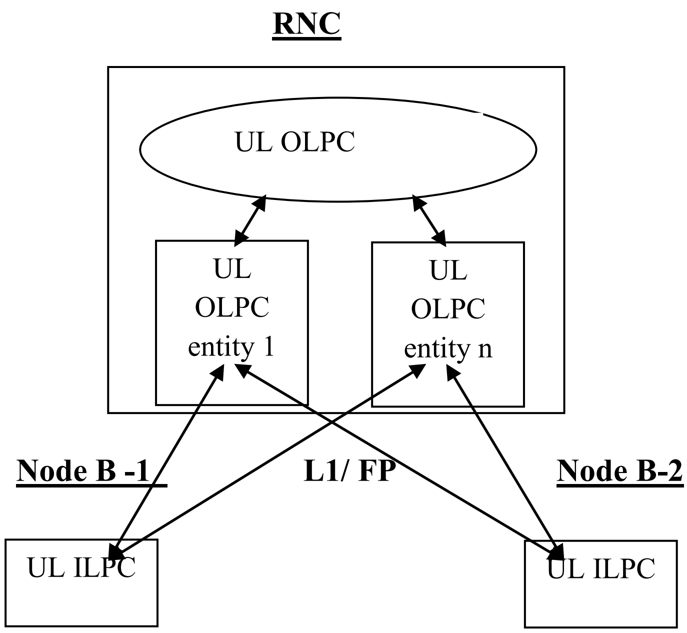

Figure 3.1: Functional split of OLPC

3.2.1 OLPC entity

The major task of the OLPC entity is to monitor the uplink quality by measuring the block error rate of the data frames received and thereby calculating the needed SIR changes to have a sufficient quality for the service. The OLPC entities can be in one of the three states (active, semi-active or inactive) which are controlled by the OLPC controller. Active state entity can send either SIR target up or down command, semi-active entity can send only SIR target up command and inactive entity cannot send either SIR target up or down command. OLPC entity algorithms are classified based on whether E-DCH or DCH channels are used for the service.

Algorithm 1 is used when there is at least one E-DCH channel in the service [16]. Algorithm 1 is a three step process.

1. OLPC entity measures the BLER of all DCH and E-DCH channels and sends it to OLPC controller via activity reports. OLPC entity then receives activity control reports from OLPC controller containing information on ideal BLER target and estimated BLER of DCH entity or E-DCH entity that has experienced the worst quality depending on the chosen active entity. The dynamic BLER is calculated every activity report period to determine the change required in target SIR value.

   E-DCH BLER is measured based on the window implementation. Figure 3.2 describes the BLER window implementation [16]. BLER measurement is started inside an activity report period when the BLER window is started. BLER is measured in frames and is multiplied by TTI to convert it into time. Equation (3.1) below gives the formula for calculating BLER.

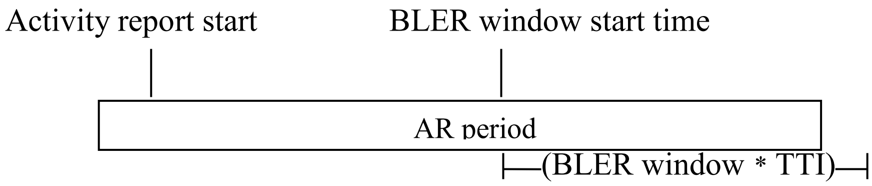

Figure 3.2: BLER window implementation

$$BLER = \frac{\left(\sum_{i=1}^{BLER_{window}} \frac{number\_of\_retransm_i}{number\_of\_transm_i} \right)}{BLER_{window}} \qquad (3.1)$$

Where *number_of_retransm* indicates the number of HARQ retransmissions for the i[th] transport block and $BLER_{window}$ indicates the time period of the window.

DCH BLER is measured based on the last frame received before the activity report period ended given by equation (3.2).

$$BLER = number\ of\ CRC\ not\ ok\ TBs / number\ of\ all\ TBs \tag{3.2}$$

Dynamic BLER is then calculated from equation (3.3) or (3.4) depending on the situation.

$$\begin{aligned} &dynamic\_BLER\_target\_DCH = ideal\_BLER\_target\_DCH + \\ &+ DCH\_slope\_of\_the\_curve \cdot (ideal\_BLER\_target - BLER\_EDCH) \end{aligned} \tag{3.3}$$

Where *BLER_EDCH* is the block error rate measured with E-DCH channel and *DCH_slope_of_the_curve* is a constant.

$$\begin{aligned} &dynamic\_BLER\_target\_EDCH = ideal\_BLER\_target\_EDCH + \\ &+ EDCH\_slope\_of\_the\_curve \cdot (ideal\_BLER\_target - BLER\_DCH) \end{aligned} \tag{3.4}$$

Where *BLER_DCH* is the block error rate measured with DCH channel and E*DCH_slope_of_the_curve* is a constant.

Determine the SIR step change based on equation (3.5) if it is for DCH and equation (3.6) if it is for E-DCH.

$$\begin{aligned} &sir\_up\_step\_size = (1 - dynamic\_BLER\_Target\_DCH) \cdot stepsizeDCHBLER \\ &sir\_down\_step\_size = BLER\_Target\_DCH \cdot stepizeDCHBLER \end{aligned} \tag{3.5}$$

Where *stepsizeDCHBLER* is a constant.

$$\begin{aligned} &sir\_up\_step\_size = (1 - dynamic\_BLER\_Target\_EDCH) \cdot stepsizeEDCHBLER \\ &sir\_down\_step\_size = BLER\_Target\_EDCH \cdot stepizeEDCHBLER \end{aligned} \tag{3.6}$$

Where *stepsizeEDCHBLER* is a constant.

2. OLPC entity receives quality information from macro diversity and combining unit. The CRC's of the frame transport blocks are checked. If all transport blocks are error free, SIR down step size is sent by the active entity. If any one of the transport block is erroneous, SIR up step size is sent by the active entity.

Algorithm 2 is used when there are only E-DCH channels in the call. OLPC entity receives either HARQ retransmission threshold information from MAC-es or HARQ failure information from frame protocol. If frame is ok, then BLER estimation is equal to 0 else BLER estimation is equal to 1 [7]. Change in SIR (ΔSIR) required is calculated using equation (3.7).

$$\Delta SIR = step\_size\,(BLER\_estimation - BLER\_target) \qquad (3.7)$$

Where *step_size* is a constant and *BLER_target* is a fixed value obtained from OLPC controller.

3.2.2 OLPC controller

The major task of OLPC controller is the selection of active entity and calculating the new SIR set point. All entities send activity reports to OLPC controller synchronously with fixed activity reporting period. Based on these activity reports, activity states of the entities are selected for the duration of next reporting period.

OLPC controller algorithm starts when an activity report is received from some OLPC entity. If the difference between the measured BLER and ideal BLER target for the entity that just sent activity report is greater than for the entity that has so far been selected as active, then the new entity will be selected as active. When the active entity sends SIR change request, new SIR will be calculated based on equation (3.8) [16].

$$new\_initial\_SIR = old\_initial\_SIR + \Delta SIR \qquad (3.8)$$

Where ΔSIR *is the change in SIR value required.*

3.3 Shortcomings of the feature

There are two shortcomings in the feature, one with very high HSUPA traffic in the cell and the other in case of very low HSUPA traffic in the cell [18].

3.3.1 High HSUPA traffic in the cell

When the number of HSUPA users in the cell is greater than 35, the data transmitted in the E-DCH MAC-d flows tend to be more like bursts even if the transmission is continuous. Therefore, OLPC starts using moderate values of BLER target rather than using high BLER target values of the continuous data instead. This leads to decrease in the gain achieved in terms of average user throughput and cell throughput as expected from the feature.

To overcome this problem, once the number of HSUPA users exceeds 35 in the cell, there is no distinction between bursty and continuous traffic type users. All the users are treated as continuous and only the higher BLER target values of continuous traffic type is used in calculating SIR target values. This has resulted in achieving better cell throughput values when HSUPA traffic is very high within the cell. The detailed analysis on this is done in later chapters with simulations.

3.3.2 Low HSUPA traffic in the cell

When the number of HSUPA users in the cell is less than 3 and if the users are transmitting continuously as in the case of FTP upload on top of TCP, OLPC uses high BLER target values which in turn results in more HARQ retransmissions, more RLC retransmissions and more TCP (Transmission Control Protocol) retransmissions. All these add up to the delay in TCP acknowledgements and as a result end to end downlink TCP throughput reduces significantly.

To overcome this problem, when the number of HSUPA users in the cell is less than or equal to 3 the HSUPA dynamic BLER feature is not activated. This helps in avoiding the delay build-up in TCP. The detailed analysis on this is done in later chapters with the help of simulations.

Chapter 4

Simulator implementation

The simulator to evaluate ‘Dynamic HSUPA BLER’ feature is implemented in Matlab. The actual wireless channel is not simulated; instead the measurements from the Nokia Networks system test logs are used. The inputs to the simulator are noise rise target of the cell, measured BLER, frame rate and number of HARQ retransmissions, which help in determining the traffic type of the UE. The outputs of the simulator are average user throughput and cell throughput. The simulator implementation is divided into 5 steps:

1. From the noise rise target of the cell, determine the total uplink load factor of the cell [19].
2. From the estimated BLER, frame rate and number of HARQ retransmissions determine the traffic type of the user and then calculate the dynamic BLER, the change in SIR required and also the target SIR. The estimated BLER value increases as the number of users within the cell increases. Target SIR Values of all the users are saved in excel sheet which is later used for other calculations in the simulator [16].
3. From the target SIR values of the users, uplink load factor is calculated for every user within the cell, by calculating individual load factors of all the uplink channels in a UE [20].
4. A simple scheduler algorithm is used to schedule all the users in a cell, such that the target noise rise level is not exceeded. Activity factor of each UE is determined [21].
5. Average user throughput and cell throughput is now calculated by considering fixed bearer bit rate [21].

The implementation is done for both 2ms and 10ms HSUPA users. The detailed implementation procedure is explained in this chapter.

4.1 Total uplink load factor of a cell

Noise rise in the system is defined to be 8 db. Total uplink load factor of a cell is calculated using equation (4.2). Noise rise is given by equation (4.1).

Noise rise = 1/ (1- η) (4.1)

Where *η* is the uplink load factor.

Total uplink load factor= (1-10 $^{(-\text{Noise rise}/10)}$*)* (4.2)

4.2 Dynamic BLER, ΔSIR and target SIR

Traffic type of the user is determined from the frame rate as discussed in chapter 3. By knowing the idea BLER target of a particular traffic type, it is now easy to measure the dynamic BLER from the received BLER measurements of the users. Dynamic BLER is calculated using equation (4.3). The change is SIR required is calculated using equation (4.4) and the new target SIR is calculated using equation (4.5).

$$\begin{aligned} &dynamic\_BLER\_target\_EDCH = ideal\_BLER\_target\_EDCH + \\ &+ EDCH\_slope\_of\_the\_curve \cdot (ideal\_BLER\_target - BLER\_DCH) \end{aligned} \tag{4.3}$$

Where *EDCH_slope_of_the_curve* is a constant and *BLER_DCH* is measured block error rate for DCH channel.

$$\begin{aligned} &sir\_up\_step\_size = (1 - dynamic\_BLER\_Target\_EDCH) \cdot stepsizeEDCHBLER \\ &sir\_down\_step\_size = BLER\_Target\_EDCH \cdot stepizeEDCHBLER \end{aligned} \tag{4.4}$$

Where *stepsizeEDCHBLER* is a constant.

$$new\_initial\_SIR = old\_initial\_SIR + \Delta SIR \tag{4.5}$$

Where ΔSIR is the change in SIR value required.

4.3 Uplink load factor per user

To determine the uplink load factor per user it is necessary to calculate the load factor of all the uplink channels DPCCH, HS-DPCCH, E-DPCCH and E-DPDCH.

4.3.1 DPCCH load factor

Load factor L_{DPCCH} is calculated for the DPCCH overhead from the planned SIR target of the DPCCH using equation (4.6).

$$L_{DPCCH} = \frac{1}{1+\frac{SF_{DPCCH}}{SIR_{DPCCH}}} \qquad (4.6)$$

Where SF_{DPCCH} is the spreading factor of the UL DPCCH and SIR_{DPCCH} is the value of the SIR target calculated from the equation (4.5).

Converting equation (4.6) into logarithmic scale yields equation (4.7).

$$L_{DPCCH} = 10^{((SIR - 10log10\ (SF))/10)} \qquad (4.7)$$

Where SIR is expressed in db.

Considering low power offsets, equation (4.7) becomes equation (4.8).

$$L_{DPCCH} = 10^{((SIR - 10log10\ (SF) + DPCCH\ power\ offset)/10)} \qquad (4.8)$$

DPCCH power offset values are based on table 4.1 [22].

DPCCH Power offset values	***SF4***	***2SF4***	***2SF2***	***2SF2_2SF4***
10ms user	*-2*	*-3*	*-5*	*0*
2ms user	*-1*	*-2*	*-4*	*-6*

Table 4.1: DPCCH power offset values

4.3.2 HS-DPCCH load factor

Load factor $L_{HS\text{-}DPCCH}$ is calculated for the HS-DPCCH overhead using equation (4.9).

$$L_{HSDPCCH} = 1/\ (1+ (SF_{DPCCH}/PO_{HSDPCCH}\ .SIR_{DPCCH})) \qquad (4.9)$$

Where SIR_{DPCCH} is the value of the SIR target calculated from the estimated uplink quality, SF_{DPCCH} is the spreading factor of the UL DPCCH and $PO_{HSDPCCH}$ is obtained from equation (4.10) and (4.11).

$$PO_{HSDPCCH} = P_{cqi} \cdot \left[(1 - P_{sho}) \cdot v_{nonsho} \cdot \left(\frac{\beta_{hs}}{\beta_c} \right)^2_{nonsho} + P_{sho} \cdot v_{sho} \cdot \left(\frac{\beta_{hs}}{\beta_c} \right)^2_{sho} \right] \quad (4.10)$$

$$v_{nonsho} = \frac{\min(2 \cdot \mathrm{CQI}_{\mathrm{rep,nonsho}}, \mathrm{CQI}_{\mathrm{fbc,nonsho}})}{\mathrm{CQI}_{\mathrm{fbc,nonsho}}}$$
$$v_{sho} = \frac{\min(2 \cdot \mathrm{CQI}_{\mathrm{rep,sho}}, \mathrm{CQI}_{\mathrm{fbc,sho}})}{\mathrm{CQI}_{\mathrm{fbc,sho}}} \quad (4.11)$$

Where P_{sho} is the proportion of the soft handovers in the CQI (Channel Quality Indicator) power offset definition and P_{cqi} is the proportion of the CQI feedback transmission in HS-DPCCH power overhead definition. Quantities $(\beta_{hs}/\beta_c)_{nonsho}$ and $(\beta_{hs}/\beta_c)_{sho}$ are representing the quantized HS-DPCCH/DPCCH amplitude ratios β_{hs}/β_c in the non-soft handover and soft handover states respectively. These amplitude ratio values depend on the ACK, NACK and CQI values as shown in table 4.2 [23]. Quantities $CQI_{rep,\ nonsho}$ and $CQI_{rep,\ sho}$ are representing the CQI repetition factors in the non-soft handover and soft handover states consequently. $CQI_{fbc,\ nonsho}$ and $CQI_{fbc,\ sho}$ are representing the CQI feedback cycles (in milliseconds) in the non-soft handover and soft handover states consequently.

Signalled values for Δ_{ACK}, Δ_{NACK} and Δ_{CQI}	Quantized amplitude ratios $A_{hs} = \beta_{hs}/\beta_c$
9	38/15
8	30/15
7	24/15
6	19/15
5	15/15
4	12/15
3	9/15
2	8/15
1	6/15
0	5/15

Table 4.2: Quantization of the power offset for HS-DPCCH

Converting equation (4.9) into logarithmic scale yields equation (4.12).

$L_{HS\text{-}DPCCH} = 10\text{^}((10\log10\ (PO) + 10\log10\ (L_{DPCCH}))/10)$ (4.12)

4.3.3 E-DPCCH load factor

Load factor $L_{E\text{-}DPCCH}$ is calculated for the E-DPCCH overhead using equation (4.13).

$$L_{E\text{-}DPCCH} = L_{DPCCH} \cdot A_{ec}^2 \tag{4.13}$$

Where A_{ec} is the gain factor for E-DPCCH (β_{ec})/ gain factor for DPCCH (β_c)'.

A_{ec} is the E-DPCCH power offset which is signalled by the higher layers as shown in table 4.3 [23].

Signalled values for $\Delta_{E\text{-}DPCCH}$	Quantized amplitude ratios $A_{ec} = \beta_{ec}/\beta_c$
8	30/15
7	24/15
6	19/15
5	15/15
4	12/15
3	9/15
2	8/15
1	6/15
0	5/15

Table 4.3: Quantization of the power offset for E-DPCCH

Converting equation (4.13) into logarithmic scale yields equation (4.14).

$$L_{E\text{-}DPCCH} = 10^{((10\log10\,(LDPCCH)\,+\,10\log10\,(Aec2))/10)} \tag{4.14}$$

4.3.4 E-DPDCH load factor

Load factor E-DPDCH depends on the E-DCH transport bock size chosen by UE to transmit in uplink and the corresponding power offset required for this transmission. Scheduler in Node B and E-TFCI selection in UE is responsible for choosing the transport block size and defining the required power offset value. Load factor $L_{E\text{-}DPDCH}$ is calculated for the E-DPDCH overhead using equation (4.15).

$$L_{E\text{-}DPDCH} = L_{DPCCH} \cdot \textit{Absolute grant value} \tag{4.15}$$

$$\textit{Absolute grant value} = A_{ed} \cdot \textit{Number of codes} \tag{4.16}$$

Where A_{ed} is the 'Gain factor for E-DPDCH (β_{ed})/ gain factor for DPCCH (β_c)'. A_{ed} is the E-DPDCH power offset value which is signalled by the scheduler in Node B, in terms of absolute grants as shown in annexure 1. This value depends on the UE power headroom and E-DCH buffer status. All the index values from 2 to 31 are mapped to a certain power value that the UE can use for its transmission. Scheduling grant is now mapped to the corresponding ETFCI values from the scheduler grant to ETFCI table and the ETFCI is mapped to the corresponding transport block size from the ETFCI to TB (Transport Block) size tables [24]. The values in the tables depend on the spreading factors used for data transmission and also on the transmission time interval. ETFCI to TB size mapping tables are shown in annexure 2 and scheduling grant to ETFCI mapping tables are shown in annexure 1.

For the purpose of simulation, MAC-d PDU (Packet Data Unit) size is fixed to 336 bits including both header and data part. In HSUPA, we consider that one transport block has only one MAC-e/ MAC-i PDU and each MAC-e/MAC-i PDU has one MAC-d flow in it. MAC-e or MAC-i PDU size is now determined using equation (4.17) and (4.18) respectively.

$$Total\_bits\_in\_MACe = Number\_of\_MACes\_PDUs \,.\, (DDI\_size + TSN\_size + Num\_MACd\_PDUs\_size + (Total\_bits\_in\_MAC\_d \,.\, Number\_of\_MACd\_PDUs)) \tag{4.17}$$

Where *DDI_size* indicates the logical channel id, MAC-d flow id and size of the MAC-d PDU's concatenated into the associated MAC-es PDU, *TSN_size* indicates the transmission sequence number of MAC-es PDU’s, *Num_MACd_PDUs_size* indicates the size for number of MAC-d PDU's identifier and *Number_of_MACd_PDUs* indicates the number of consecutive MAC-d PDU's in one MAC-es PDU.

$$Total\_bits\_in\_MACi=Number\_of\_MACes\_PDUs.(Si+TSNi) +Number\_of\_MACd\_PDUs \,.\, (LCHIDi+Li+Fi+Total\_bits\_in\_MAC\_d) \tag{4.18}$$

Where *LCHIDi* field provides identification of the logical channel at the receiver and the re-ordering buffer destination of a reordering SDU, *TSNi* field is used for reordering purposes to support in-sequence delivery to higher layers, *Si* is the segmentation indication of MAC-i SDU, *Li* provides the length of the reordering SDU, *Fi* is the flag indicating if more fields are present in MAC-i header or not (‘0’ indicates Flag is followed by additional set of *LCH-ID, L,* and *F* field; ‘1’ indicates Flag is followed by MAC-is PDU) and *Number_of_MACd_PDU’s* indicates the number of consecutive MAC-d PDU's in one MAC-es PDU.

Figure 4.1 and figure 4.2 show the structure of MAC-e and MAC-i PDU’s respectively [14].

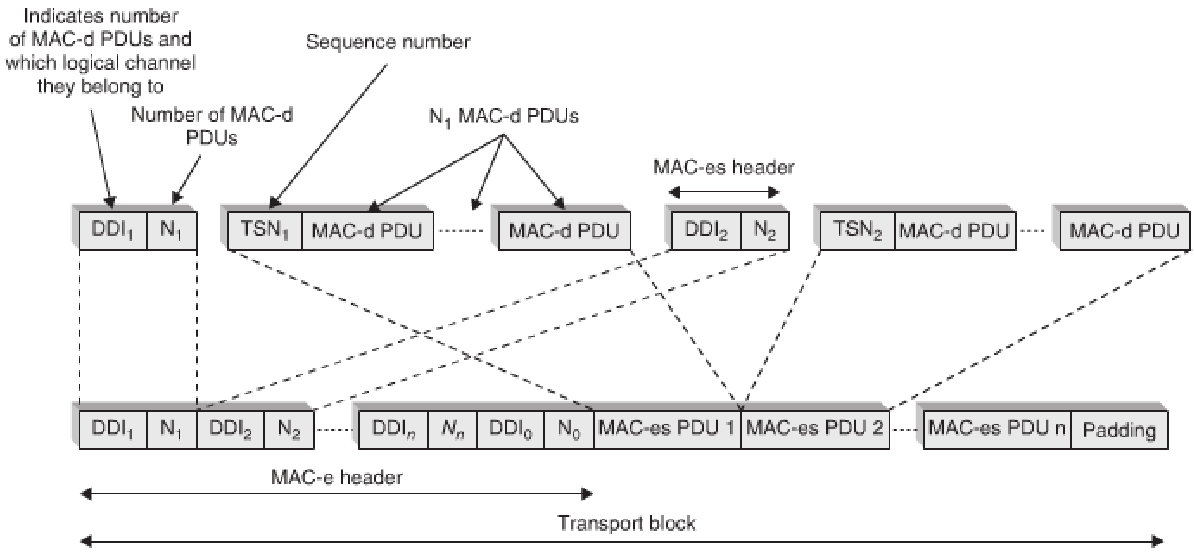

Figure 4.1: MAC-e PDU structure

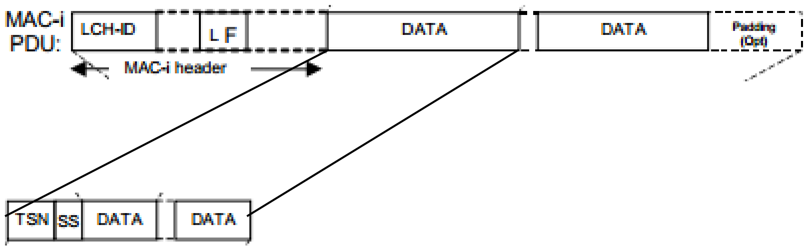

Figure 4.2: MAC-i PDU structure

Once the MAC-e or MAC-i PDU size is determined, we can obtain the E-DCH transport block size that can carry the entire PDU in a single TTI. Therefore we obtain the corresponding ETFCI index value from the table in appendix 3. The corresponding scheduling grant needed by the Node B is obtained from the table in appendix 2. The scheduling grant values are mapped to the power offset values as shown in appendix 1. The load factor of E-DPDCH is now calculated from equation (4.15).

Converting equation (4.15) into logarithmic scale yields equation (4.19).

$$L_{E\text{-}DPDCH} = 10^{((10\log10\,(LDPCCH)\,+\,10\log10\,(\text{Absolute grant value}))/10)} \qquad (4.19)$$

4.3.5 Load factor per user

Load factor depends on the duration of time the UE was transmitting in uplink and also on the target SIR required to achieve quality transmission. It is given by equation (4.20).

Total load per user = (1+i) . (L_{DPCCH} + $L_{HSDPCCH}$ + Activity factor . ($L_{E\text{-}DPCCH}$ + $L_{E\text{-}DPDCH}$))

(4.20)

Where *i* is the interference factor from other cells and is equal to 0.5, *Activity factor* is calculated in next section and L_{DPCCH}, $L_{HSDPCCH}$, $L_{E\text{-}DPCCH}$ and $L_{E\text{-}DPDCH}$ are already calculated above.

4.4 Activity factor of users

Considering all the users in a cell are similar with respect to spreading factors used, modulation used, transport block sizes used etc and also considering all the users are scheduled on a round robin approach, the activity factor of each user varies depending on the target SIR required for that particular user. It is calculated according to equation (4.21).

Activity factor (k) = ((Total uplink load factor/number of users) . (1/ (1+i)) - L_{DPCCH} (k) + $L_{HSDPCCH}$ (k))/ ($L_{E\text{-}DPCCH}$ (k) + $L_{E\text{-}DPDCH}$ (k))

(4.21)

Where *k* indicates the k^{th} user in the cell.

4.5 Average user throughput and cell throughput

Once the activity factors of all HSUPA users are known and by considering a fixed radio bearer bit rate, average user throughput and cell throughput are determined using equation (4.22) and (4.23) respectively.

Average user throughput (number of users) = (Sum (Activity factors of all the users) . Bit rate of radio bearer)/number of users (4.22)

Cell throughput (number of users) = Average throughput (number of users) . number of users (4.23)

Where Bit rate of radio bearer is either 32Kbps or 64Kbps.

Chapter 5

Analysis and simulation results

To understand the benefits of 'Dynamic BLER feature' we simulate 3 scenarios with 10ms TTI users and 2ms TTI users and then analyze the results. In the first scenario, we consider 10 HSUPA users. In the second scenario, we consider 1 HSUPA user. In the third scenario, we consider 72 HSUPA users.

5.1 With 10 HSUPA users in the cell

In this section, the cell throughput is first calculated without the feature being activated (Ideal BLER target = 10%). Next, the cell throughput is calculated with the feature activated (different ideal BLER target values based on the traffic types). The analysis is done for both 10ms and 2ms users. The results are then compared and analyzed.

5.1.1 Total uplink load factor

Since the noise rise target of the cell is 8 db, total uplink load factor is equal to 84.15% calculated using equation (4.2).

5.1.2 Dynamic BLER, ΔSIR and target SIR

Let us consider we have 10 users within a cell. The estimated BLER values and frame rate for all the 10 users based on the Nokia Networks system test logs are shown in table 5.1. Also shown in the table is the target SIR calculated with and without the feature. Dynamic BLER, ΔSIR and target SIR are measured using equation (4.3), (4.4) and (4.5) respectively.

User number	**Estimated BLER value**	**Frame rate**	**Traffic types**	**Target SIR (without feature)**	**Target SIR (With feature)**
1	0.3	>10(10ms),50(2ms)	Continuous	5.6	2.4
2	0.27	>10(10ms),50(2ms)	Continuous	5.48	2.46
3	0.25	<10(10ms),50(2ms)	Bursty	5.4	5.4
4	0.22	<10(10ms),50(2ms)	Bursty	5.28	5.28
5	0.21	>10(10ms),50(2ms)	Continuous	5.24	2.58
6	0.19	<10(10ms),50(2ms)	Bursty	5.16	5.16
7	0.16	>10(10ms),50(2ms)	Continuous	5.04	2.68
8	0.15	<10(10ms),50(2ms)	Bursty	5	5
9	0.14	>10(10ms),50(2ms)	Continuous	4.96	2.72
10	0.10	<10(10ms),50(2ms)	Bursty	4.8	4.8

Table 5.1: BLER to SIR mapping

From table 5.1, we observe the difference in target SIR with and without the feature. This results in significant reduction of uplink interference caused by the user transmissions.

5.1.3 Load factor of uplink channels

Load factors of DPCCH, HS-DPCCH, E-DPCCH and E-DPDCH are shown in table 5.2 and 5.3 that are calculated based on equations (4.8), (4.12), (4.14) and (4.19) respectively without and with the feature. To calculate the load factor of HS-DPCCH and E-DPCCH quantized amplitude ratios were considered based on the signalled values depending on 10ms or 2ms users. To calculate the E-DCH TB size, MAC-d PDU size of 336 bits is considered. E-DCH TB size varies depending on 10ms and 2ms users and is calculated using equation (4.17) and (4.18).

User number	L_{DPCCH} *(10ms/2ms)*	$L_{HSDPCCH}$ *(10ms/2ms)*	$L_{E\text{-}DPCCH}$ *(10ms/2ms)*	$L_{E\text{-}DPDCH}$ *(10ms/2ms)*
1	0.448/0.356	0.244/0.193	0.287/0.912	1.793/4.446
2	0.436/0.346	0.237/0.188	0.279/0.887	1.745/4.324
3	0.428/0.340	0.233/0.185	0.274/0.870	1.713/4.245
4	0.416/0.330	0.226/0.180	0.266/0.847	1.666/4.130
5	0.412/0.327	0.224/0.178	0.264/0.839	1.651/4.092
6	0.405/0.321	0.220/0.175	0.259/0.824	1.621/4.017
7	0.394/0.313	0.214/0.170	0.252/0.801	1.576/3.908
8	0.390/0.310	0.212/0.168	0.250/0.794	1.562/3.872
9	0.387/0.307	0.210/0.167	0.247/0.787	1.548/3.836
10	0.373/0.296	0.202/0.161	0.238/0.758	1.492/3.698

Table 5.2: Load factors of channels (without feature)

User number	L_{DPCCH} *(10ms/2ms)*	$L_{HSDPCCH}$ *(10ms/2ms)*	$L_{E\text{-}DPCCH}$ *(10ms/2ms)*	$L_{E\text{-}DPDCH}$ *(10ms/2ms)*
1	0.214/0.170	0.116/0.092	0.137/0.436	0.858/2.128
2	0.217/0.172	0.118/0.094	0.139/0.442	0.870/2.157
3	0.428/0.340	0.233/0.185	0.274/0.870	1.713/4.245
4	0.416/0.330	0.226/0.180	0.266/0.847	1.666/4.130
5	0.223/0.177	0.121/0.096	0.143/0.454	0.894/2.218
6	0.405/0.321	0.220/0.175	0.259/0.824	1.621/4.017
7	0.228/0.181	0.124/0.098	0.146/0.465	0.915/2.269
8	0.390/0.310	0.212/0.168	0.250/0.794	1.562/3.872
9	0.231/0.183	0.125/0.099	0.147/0.468	0.924/2.290
10	0.373/0.296	0.202/0.161	0.238/0.758	1.492/3.698

Table 5.3: Load factors of channels (with feature)

5.1.4 Average user throughput and cell throughput

Average user throughput with 10 users in the cell improved from 84 Kbps to 124 Kbps in case of 10ms users and it improved from 167 Kbps to 245 Kbps in case of 2ms users. Therefore, cell throughput also increased from 841 Kbps to 1.24 Mbps in case of 10ms users and it increased from 1.67 Mbps to 2.45 Mbps in case of 2ms users. Interference factor of 0.5 is considered for the calculations. The plots for cell throughput are shown in figure 5.1 and 5.2 for 10 ms users and in figure 5.3 and 5.4

for 2ms users.

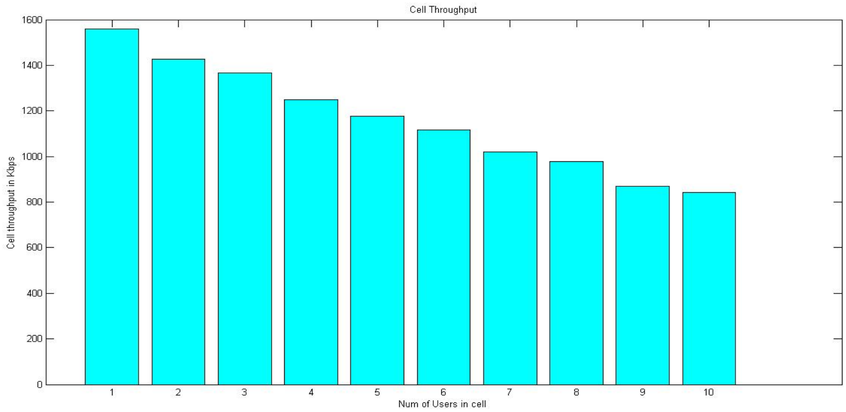

Figure 5.1: Cell throughput with 10 10ms users (HSUPA Dynamic BLER Feature inactive)

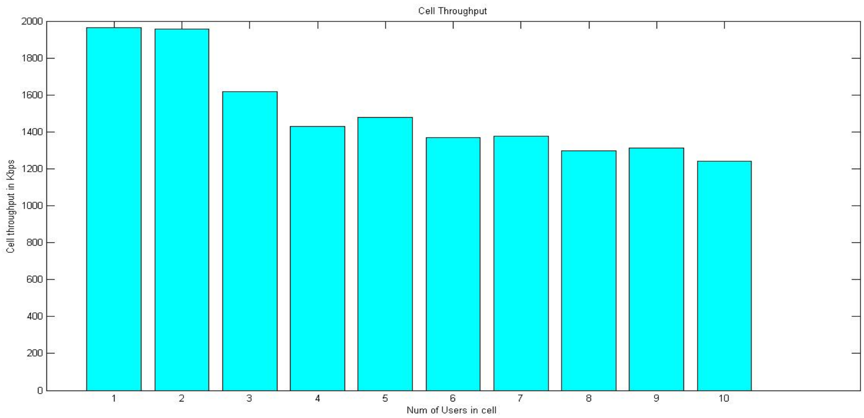

Figure 5.2: Cell throughput with 10 10ms users (HSUPA Dynamic BLER Feature active)

Figure 5.1 and 5.2 shows the variation of cell throughput with respect to the number of users within the cell. All the users are of same type i.e. 10ms TTI, 32Kbps bearer bit rate and spreading factor 2SF2. As the number of users increase in the cell, the cell throughput decreases due to the increase in interference. By comparing figure 5.1 and 5.2, we observe the improvement in cell throughput by about 400 Kbps with 10 users when the feature is active.

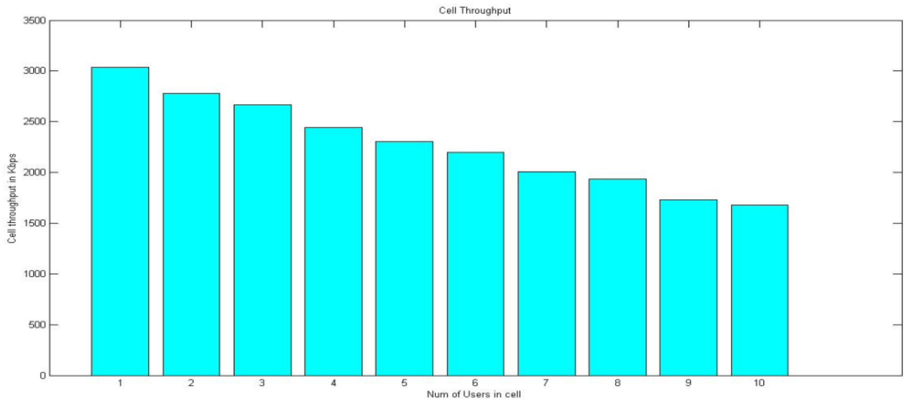

Figure 5.3: Cell throughput with 10 2ms users (HSUPA Dynamic BLER Feature inactive)

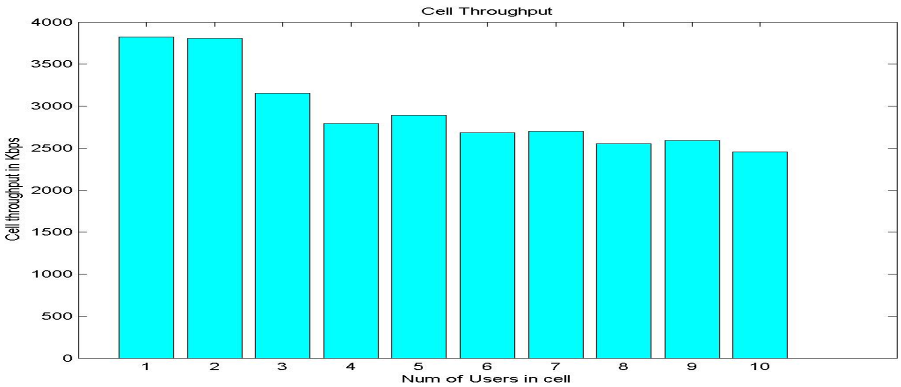

Figure 5.4: Cell throughput with 10 2ms users (HSUPA Dynamic BLER Feature active)

Figure 5.3 and 5.4 shows the variation of cell throughput with respect to the number of users within the cell. All the users are of same type i.e. 2ms TTI, 64Kbps bearer bit rate and spreading factor 2SF2 x 2SF4. As the number of users increase in the cell, the cell throughput decreases due to the increase in interference. By comparing figure 5.3 and 5.4, we observe the improvement in cell throughput by about 700 Kbps with 10 users when the feature is active.

5.2 With 1 HSUPA user in the cell

In this section one of the two shortcomings of the feature is well understood and a solution for it is also discussed. When the feature is not activated ideal BLER target values of 10% is used to calculate target SIR value, but when the feature is activated and say the user is of continuous traffic type, ideal BLER target value of 31.6% is used. Higher ideal BLER target value results in higher HARQ retransmissions and also increases the probability of RLC retransmissions [25]. All these factors result in the increase of TCP round trip time (delay in TCP ACK) and thus reduces the end to end TCP throughput in downlink [26]. A simple simulator is implemented to show the effect of increase in ideal BLER target values on TCP round trip time and thus on end to end TCP throughput. The implementation is explained in this section along with the simulation results.

Consider a TCP segment size both in uplink and downlink. Calculate the number of HARQ packets needed to transmit this TCP segment using equation (5.1) and (5.2) [26].

$$Number\_of\_HARQ\_Packets\_UL=ceil\ (SS\_UL/MAC\_E\_PDU\_size\_UL) \tag{5.1}$$

$$Number\_of\_HARQ\_Packets\_DL=ceil\ (SS\_DL/MAC\_E\_PDU\_size\_DL) \tag{5.2}$$

Where *SS_UL* is the TCP segment size in uplink and *SS_DL* is the TCP segment size in downlink.

Now determine the number of HARQ packets that require one, two and three retransmissions using equation (5.3), (5.4) and (5.5) respectively [27].

$$Pb\_1RX= (1\text{-}(1\text{-}BLER\_1TX)^{(BLER\_1TX\_UL\char`^1\ .\ Number\_of\_HARQ\_Packets))} \tag{5.3}$$

$$Pb\_2RX= (1\text{-}(1\text{-}BLER\_2TX)^{(BLER\_2TX\_UL.\ \char`^2\ .\ Number\_of\_HARQ\_Packets))} \tag{5.4}$$

$$Pb\_3RX= (1\text{-}(1\text{-}BLER\_3TX)^{(BLER\_3TX\_UL.\ \char`^3\ .\ Number\_of\_HARQ\_Packets))} \tag{5.5}$$

Where *Pb_1RX* is the probability of HARQ packets that require one retransmission, *Pb_2RX* is the probability of HARQ packets that require two retransmissions, *Pb_3RX* is the probability of HARQ packets that require three retransmissions, *BLER_1TX* is the measured BLER after one retransmission, *BLER_2TX* is the measured BLER after two retransmissions and *BLER_3TX* is the measured BLER after three retransmissions.

Let us now consider that a TCP ACK is sent for every two TCP segments successfully transmitted. Therefore, HARQ round trip time can be determined using equation (5.6) and it varies depending on 10ms and 2ms users [26].

$RTT\_HARQ = Num\_TCP\_segments\_UL\_per\_round.(Number\_of\_HARQ\_Packets\_UL.HARQ\_TX + Number\_of\_HARQ\_Packets\_UL.Pb\_1RX\_UL.HARQ\_RX + Number\_of\_HARQ\_Packets\_UL.Pb\_2RX\_UL.2.HARQ\_RX + Number\_of\_HARQ\_Packets\_UL.Pb\_3RX\_UL.3.HARQ\_RX) + Num\_TCP\_segments\_DL\_per\_round.(Number\_of\_HARQ\_Packets\_DL.HARQ\_TX + Number\_of\_HARQ\_Packets\_DL.Pb\_1RX\_DL.HARQ\_RX + Number\_of\_HARQ\_Packets\_DL.Pb\_2RX\_DL.2.HARQ\_RX + Number\_of\_HARQ\_Packets\_DL.Pb\_3RX\_DL.3.HARQ\_RX)$

(5.6)

Where *RTT_HARQ* is the HARQ round trip time, *Num_TCP_segments_UL_per_round* is equal to 1, *Num_TCP_segments_DL_per_round* is equal to 2 (One TCP ACK in uplink for 2 TCP segments in downlink), *HARQ_TX* is the frame length in millisecond and *HARQ_RX* is the HARQ retransmission time in millisecond.

TCP round trip time can now be calculated using equation (5.7) [26].

$$RTT\_TCP = 2.RTT\_wire + RTT\_HARQ + (2.Number\_of\_HARQ\_Packets\_DL.(1 + Pb\_1RX\_DL + Pb\_2RX\_DL + Pb\_3RX\_DL) + Number\_of\_HARQ\_Packets\_UL.(1 + Pb\_1RX\_UL + Pb\_2RX\_UL + Pb\_3RX\_UL)).D\_HARQ \quad (5.7)$$

Where *RTT_TCP* is the TCP round trip time, *RTT_wire* is the delay caused in wired transmission part of the network and *D_HARQ* is the fixed component delay to process one HARQ frame.

Finally, TCP throughput is calculated using equation (5.8).

$$TCP\_throughput = TCP\_cong\_win\_bits / (RTT\_TCP/1000) \quad (5.8)$$

Where *TCP_cong_win_bits* is the TCP congestion window size in bits.

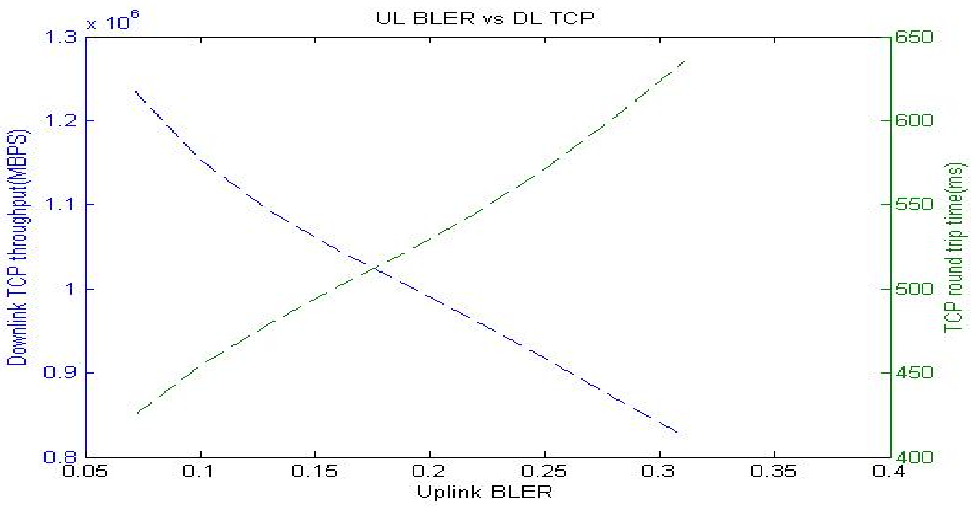

Figure 5.5: Relationship between uplink BLER, TCP round trip time and downlink TCP throughput with 1 HSUPA user in cell

Figure 5.5 shows the influence of TCP round trip time and downlink TCP throughput with the increase in uplink BLER target values. As the uplink BLER increases, TCP round trip time increases and therefore it results in decreased downlink TCP throughput because of the delays in TCP ACK's received. Therefore, with very few users in the cell the dynamic HSUPA BLER feature is not activated. The threshold limit is set to less than or equal to 3 users.

5.3 With 72 HSUPA users in the cell

In this section, the second shortcoming of the feature is well understood and a solution for it is also discussed. When the HSUPA traffic in the cell is very high, it has been proved that all data transmitted in the E-DCH MAC-d flows tends to behave more like bursts [28]. Therefore OLPC starts using moderate ideal BLER target values of bursty traffic type, even though the user is continuous traffic type. Therefore the expected gain in the cell throughput is lost.

Consider a case with 72 2ms users in the cell. The estimated BLER values and traffic types of each user is given as input to the OLPC module based on the Nokia Network system test logs. Target SIR is now calculated based on the dynamic HSUPA BLER feature for all 72 users, based on which we can derive the cell throughput. Figure 5.6 shows the plot of cell throughput with 72 users. It is observed that the cell throughput gain from the feature is not as expected with high traffic in the cell.

The solution for this shortcoming is to stop differentiating between bursty and continuous traffic types when the traffic is very high in the cell. Now, only the ideal BLER target values of 31.6% (Continuous traffic type) is used for all the users above certain threshold to determine the target SIR values. The threshold limit is set to 35 users. This results in achieving better cell throughput gain as shown in figure 5.7.

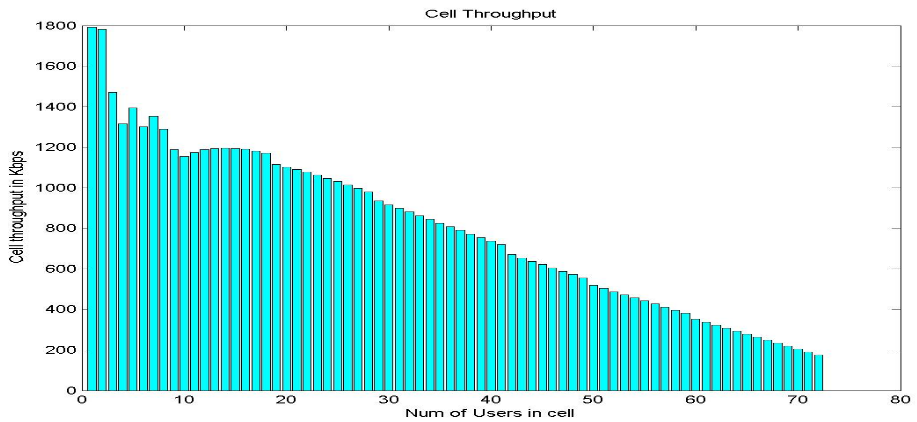

Figure 5.6: Cell throughput with 72 10ms users (Without correction to the feature)

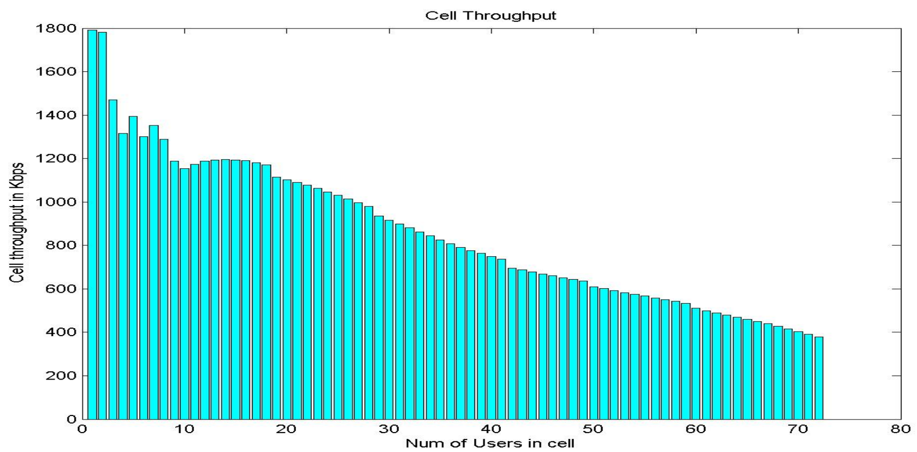

Figure 5.7: Cell throughput with 72 10ms users (With correction to the feature)

Figure 5.6 and 5.7 shows the variation of cell throughput with respect to the number of users within the cell. All the users are of same type i.e. 10ms TTI, 32Kbps bearer bit rate and spreading factor 2SF2. By comparing figure 5.6 and 5.7, we observe the improvement in cell throughput by about 250 Kbps with 72 users when the feature is active.

Chapter 6

Conclusion

High speed packet access (HSDPA + HSUPA) is said to reach 3.5 billion subscriptions by the end of 2016 according to the forecasts [29]. Therefore operators are focused on delivering impeccable and enhanced user experience for their mobile subscribers. Certain measures taken by the operators to achieve this are to build faster networks that can handle more capacity by supporting new HSPA technology features [30]. Certain features that improve the performance of HSDPA are dual cell HSDPA, three-carrier HSDPA, MIMO, High speed cell FACH etc [31]. With respect to HSUPA, features like Continuous packet connectivity, dynamic HSUPA BLER, uplink frequency domain equalizer, HS-cell FACH, 16 QAM, interference cancellation etc. reduces uplink interference, improves battery life and reduces upload time [32]. This thesis completely focused on addressing the importance of dynamic HSUPA BLER feature in reducing the uplink interference, through simulations in Matlab.

'Dynamic HSUPA BLER' is a feature in which users are classified into traffic types such as peak, bursty or continuous. Based on their traffic type, different ideal BLER targets are used to calculate the target SIR. Such efficient power control algorithm helps in responding quickly to the changes in signal and interference levels. To analyze the gain provided by the feature in terms of cell throughput, the feature has been simulated based on the system test logs. In the simulation, we consider 10 HSUPA users within the cell and then calculate the cell throughput. Cell throughput values are compared with the feature and without the feature. The gain achieved in cell throughput is around 400 Kbps in 10ms TTI case and it is 700 Kbps in 2ms TTI case. This proves that the feature has a significant importance in reducing the uplink interference and thus increasing the cell capacity.

Next, we simulated a scenario where the cell has only one user and it is of continuous traffic type. In this case, since the user is continuous, it uses higher BLER target values of 31.6% for 0^{th} HARQ retransmissions which results in low target SIR requirements. Therefore, HARQ retransmissions and RLC retransmissions will increase leading to an increase in TCP round trip time. This results in increasing the delay of TCP ACK in uplink and thus reduces the end to end TCP downlink throughput. The simulation shows that as the BLER values increase from 0.15 to 0.30, the TCP round trip time increases from 450ms to 600ms and thus reduces the TCP downlink throughput. The solution provided for this was to deactivate the feature when the number of HSUPA users within the cell is less than 3. This is one of the important factors to be considered with respect to this feature.

Finally, we simulated a scenario with 72 users of different traffic types within the cell. The observation was that once the number of users in the cell reaches a certain limit (say 35), the continuous traffic type are seen as bursty traffic type and hence moderate BLER targets of 10% are used instead of 31.6%. This results in the reduction of cell throughput significantly it was measured as 200 Kbps with 72 users in the cell. The solution for this was to stop differentiating the users into bursty and continuous traffic types and just using BLER targets of 31.6% after 35 users in the cell. The cell throughput achieved based on this was 450 Kbps with 72 users. So, we see a significant gain in cell throughput.

Once we consider both the problems of Dynamic HSUPA BLER feature by using proper solutions, this feature provides enhancement in cell capacity and cell coverage as proved from the simulation results.

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Annexure 1

Absolute grant table for 2ms TTI

Power offset index	Absolute grant index	Power offset	Power offset value	Scheduling grant to E-TFCI
37	31	(168/15)^2*6	752.64	125
36	30	(150/15)^2*6	600	125
35	29	(168/15)^2*4	501.76	125
34	28	(150/15)^2*4	400	125
33	27	(134/15)^2*4	319.21	125
32	26	(119/15)^2*4	251.75	125
31	25	(150/15)^2*2	200	123
30	24	(95/15)^2*4	160.44	123
29	23	(168/15)^2	125.44	113
28	22	(150/15)^2	100	95
27	21	(134/15)^2	79.8	79
26	20	(119/15)^2	62.93	67
25	19	(106/15)^2	49.93	59
24	18	(95/15)^2	40.11	48
23	17	(84/15)^2	31.36	38
22	16	(75/15)^2	25	35
21	15	(67/15)^2	19.95	24
20	14	(60/15)^2	16	18
19	13	(53/15)^2	12.48	14
18	12	(47/15)^2	9.81	10
17	11	(42/15)^2	7.84	6
16	10	(38/15)^2	6.41	6
15	9	(34/15)^2	5.13	4
14	8	(30/15)^2	4	2
13	7	(27/15)^2	3.24	2
12	6	(24/15)^2	2.56	2
11	-	(21/15)^2	1.96	0
10	5	(19/15)^2	1.6	0
9	-	(17/15)^2	1.28	0
8	4	(15/15)^2	1	0
7	-	(13/15)^2	0.75	0
6	-	(12/15)^2	0.64	0
5	3	(11/15)^2	0.53	0
4	-	(9/15)^2	0.36	0
3	-	(8/15)^2	0.28	0
2	2	(7/15)^2	0.21	0
1	-	(6/15)^2	0.16	0
0	-	(5/15)^2	0.11	0

Absolute grant table for 10ms TTI

Power offset index	Absolute grant index	Power offset	Power offset value	Scheduling grant to E-TFCI
37	31	(168/15)^2*6	752.64	120
36	30	(150/15)^2*6	600	120
35	29	(168/15)^2*4	501.76	120
34	28	(150/15)^2*4	400	120
33	27	(134/15)^2*4	319.21	120
32	26	(119/15)^2*4	251.75	120
31	25	(150/15)^2*2	200	120
30	24	(95/15)^2*4	160.44	120
29	23	(168/15)^2	125.44	120
28	22	(150/15)^2	100	120
27	21	(134/15)^2	79.8	120
26	20	(119/15)^2	62.93	120
25	19	(106/15)^2	49.93	114
24	18	(95/15)^2	40.11	99
23	17	(84/15)^2	31.36	80
22	16	(75/15)^2	25	66
21	15	(67/15)^2	19.95	54
20	14	(60/15)^2	16	46
19	13	(53/15)^2	12.48	38
18	12	(47/15)^2	9.81	34
17	11	(42/15)^2	7.84	30
16	10	(38/15)^2	6.41	26
15	9	(34/15)^2	5.13	24
14	8	(30/15)^2	4	18
13	7	(27/15)^2	3.24	14
12	6	(24/15)^2	2.56	12
11	-	(21/15)^2	1.96	8
10	5	(19/15)^2	1.6	6
9	-	(17/15)^2	1.28	5
8	4	(15/15)^2	1	4
7	-	(13/15)^2	0.75	2
6	-	(12/15)^2	0.64	2
5	3	(11/15)^2	0.53	2
4	-	(9/15)^2	0.36	0
3	-	(8/15)^2	0.28	0
2	2	(7/15)^2	0.21	0
1	-	(6/15)^2	0.16	0
0	-	(5/15)^2	0.11	0

Annexure 2

Transport block size table for 2ms TTI

TB Index	TB Size (bits)	TB Index	TB Size (bits)	TB Index	TB Size (bits)	TB Index	TB Size (bits)	TB Index	TB Size (bits)
0	18	30	342	60	1015	90	3008	120	8913
1	120	31	355	61	1053	91	3119	121	9241
2	124	32	368	62	1091	92	3234	122	9582
3	129	33	382	63	1132	93	3353	123	9935
4	133	34	396	64	1173	94	3477	124	10302
5	138	35	410	65	1217	95	3605	125	10681
6	143	36	426	66	1262	96	3738	126	11075
7	149	37	441	67	1308	97	3876	127	11484
8	154	38	458	68	1356	98	4019		
9	160	39	474	69	1406	99	4167		
10	166	40	492	70	1458	100	4321		
11	172	41	510	71	1512	101	4480		
12	178	42	529	72	1568	102	4645		
13	185	43	548	73	1626	103	4816		
14	192	44	569	74	1685	104	4994		
15	199	45	590	75	1748	105	5178		
16	206	46	611	76	1812	106	5369		
17	214	47	634	77	1879	107	5567		
18	222	48	657	78	1948	108	5772		
19	230	49	682	79	2020	109	5985		
20	238	50	707	80	2094	110	6206		
21	247	51	733	81	2172	111	6435		
22	256	52	760	82	2252	112	6672		
23	266	53	788	83	2335	113	6918		
24	275	54	817	84	2421	114	7173		
25	286	55	847	85	2510	115	7437		
26	296	56	878	86	2603	116	7711		
27	307	57	911	87	2699	117	7996		
28	318	58	944	88	2798	118	8290		
29	330	59	979	89	2901	119	8596		

Transport block size table for 10ms TTI

TB Index	TB Size (bits)	TB Index	TB Size (bits)	TB Index	TB Size (bits)
0	18	41	5076	82	11850
1	186	42	5094	83	12132
2	204	43	5412	84	12186
3	354	44	5430	85	12468
4	372	45	5748	86	12522
5	522	46	5766	87	12804
6	540	47	6084	88	12858
7	690	48	6102	89	13140
8	708	49	6420	90	13194
9	858	50	6438	91	13476
10	876	51	6756	92	13530
11	1026	52	6774	93	13812
12	1044	53	7092	94	13866
13	1194	54	7110	95	14148
14	1212	55	7428	96	14202
15	1362	56	7464	97	14484
16	1380	57	7764	98	14556
17	1530	58	7800	99	14820
18	1548	59	8100	100	14892
19	1698	60	8136	101	15156
20	1716	61	8436	102	15228
21	1866	62	8472	103	15492
22	1884	63	8772	104	15564
23	2034	64	8808	105	15828
24	2052	65	9108	106	15900
25	2370	66	9144	107	16164
26	2388	67	9444	108	16236
27	2706	68	9480	109	16500
28	2724	69	9780	110	16572
29	3042	70	9816	111	17172
30	3060	71	10116	112	17244
31	3378	72	10152	113	17844
32	3396	73	10452	114	17916
33	3732	74	10488	115	18516
34	3750	75	10788	116	18606
35	4068	76	10824	117	19188
36	4086	77	11124	118	19278
37	4404	78	11178	119	19860
38	4422	79	11460	120	19950
39	4740	80	11514		
40	4758	81	11796		